

-25-

5. The apparatus according to Claim 1, wherein said means further includes logic means operative to cause both characters written into said display and said background of said display to be energized according to said digital pattern and in accordance with said desired grey scale level.

6. The apparatus according to Claim 1, further including memory means for storing therein a plurality of digital patterns each one indicative of a different desired grey scale level, and  
5 means coupled to said memory means for selecting any desired one of said stored digital patterns for application to said display.

7. The apparatus according to Claim 6, wherein said electrophoretic display is a high resolution display.

8. A method of providing grey scale capability for an electrophoretic information display (EPID) of the type employing pixel selection, comprising the steps of:  
5 storing a plurality of digital patterns with each stored pattern capable when applied to an electrophoretic display to cause predetermined selected pixels in said display to be energized with respect to other pixels in said display in accordance  
10 with a desired grey scale level, and  
selecting a stored pattern for application to said display to cause said display to exhibit said grey scale level.

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9. The method according to Claim 8, wherein said energized pixels are background pixels to provide a grey background with respect to a different intensity character.

10. The method according to Claim 8, wherein said energized pixels are character pixels to provide a grey character with respect to a different intensity background.

11. The method according to Claim 10, wherein said different intensity background is indicative of white.

12. The method according to Claim 10, wherein said stored digital patterns are at least six patterns indicative of six different grey scale levels.

13. The method according to Claim 10, further including the step of "OR"ing said selected pattern with a character pattern prior to applying said character pattern to said display to display a given  
5 intensity character on a background of said selected grey scale level.

14. The method according to Claim 10, further including the step of "AND"ing said selected pattern with a character pattern prior to applying said character pattern to said display to display a given  
5 intensity background having a character impressed thereon of said selected grey scale level.

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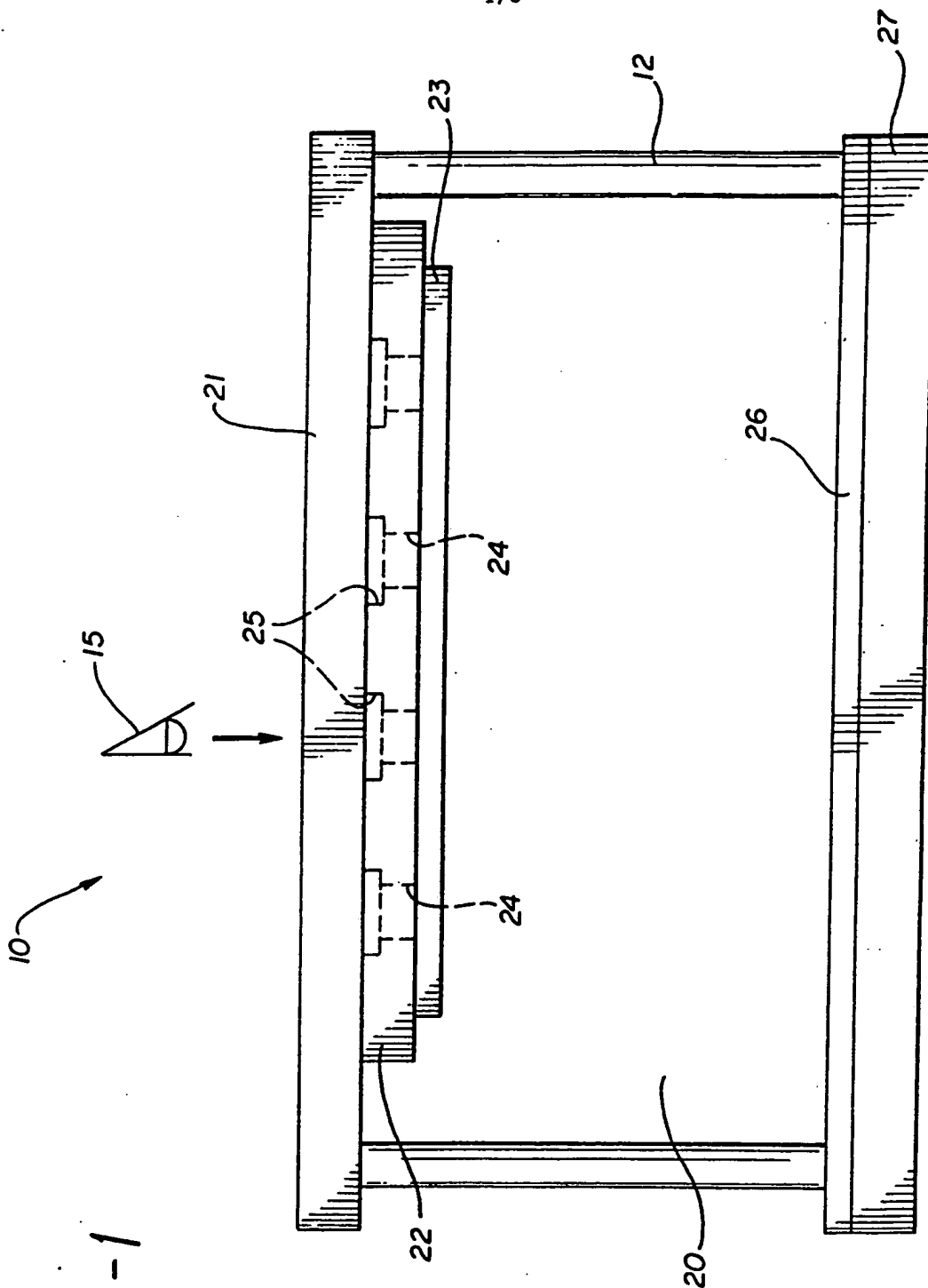


FIG-1

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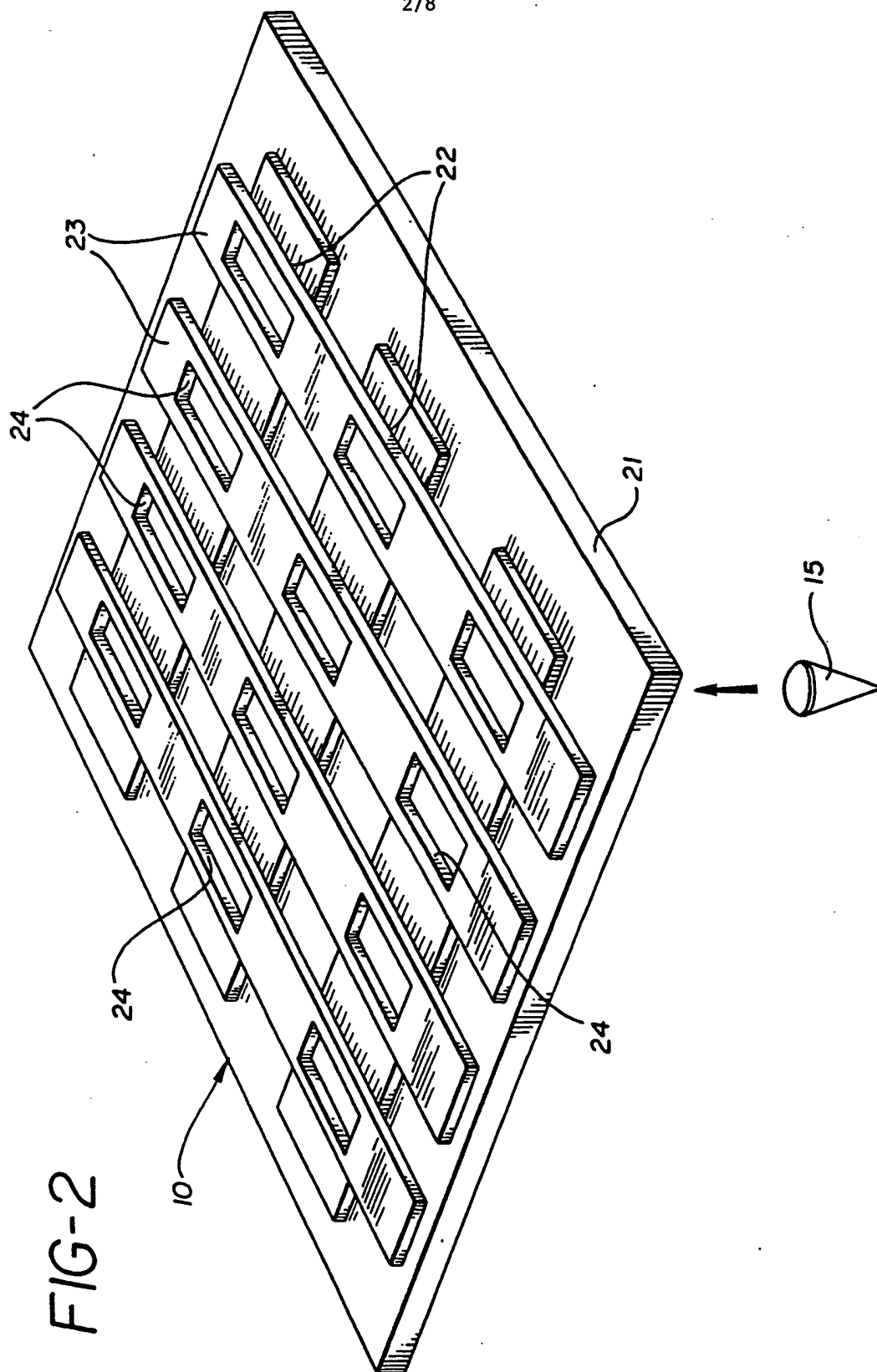


FIG-2

RESTITUTE SHEET

FIG-3

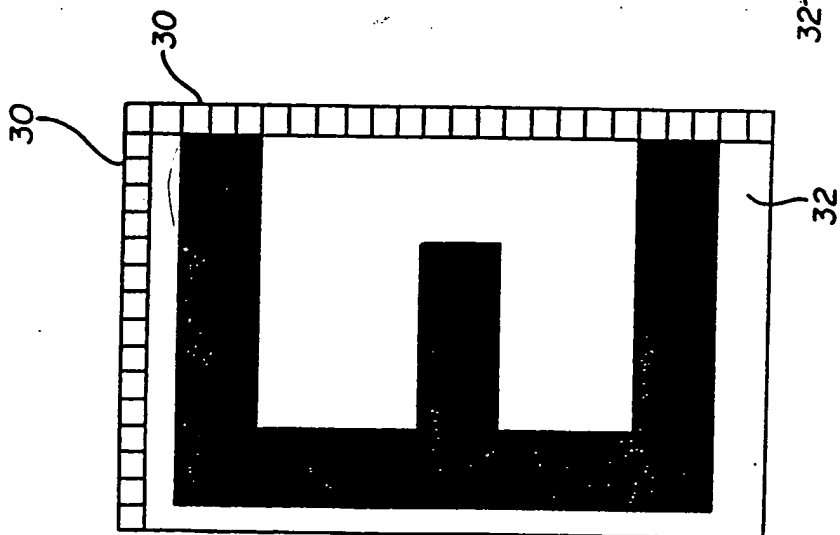


FIG-4

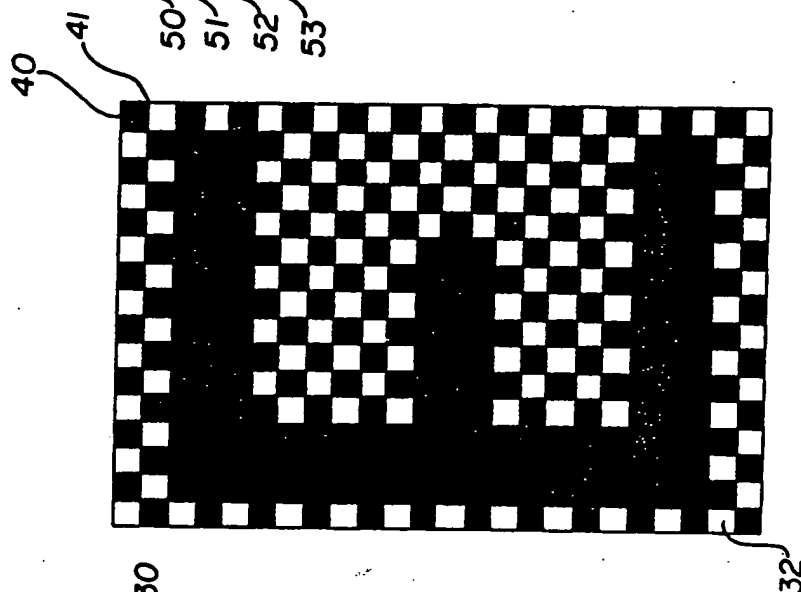
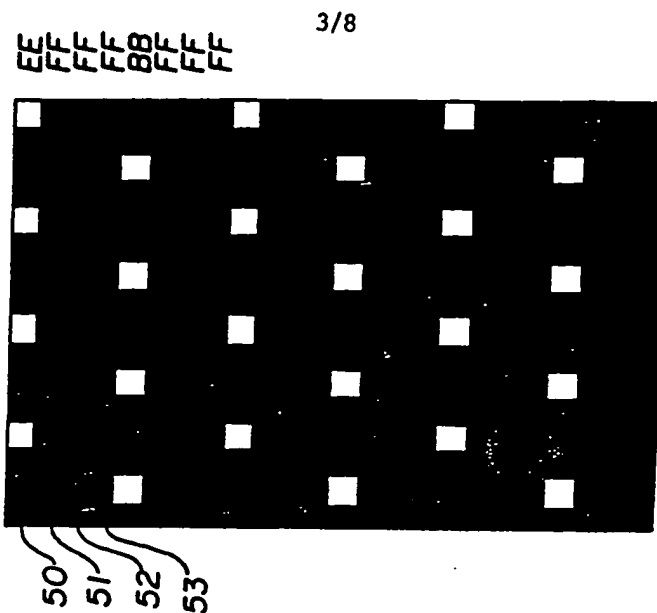


FIG-5



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EE  
FF  
FF  
FF  
88  
FF  
FF  
FF

FIG-6

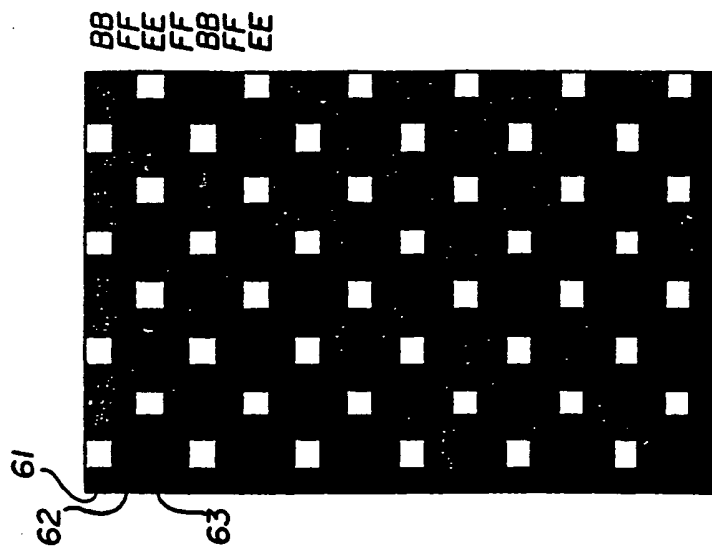


FIG-7

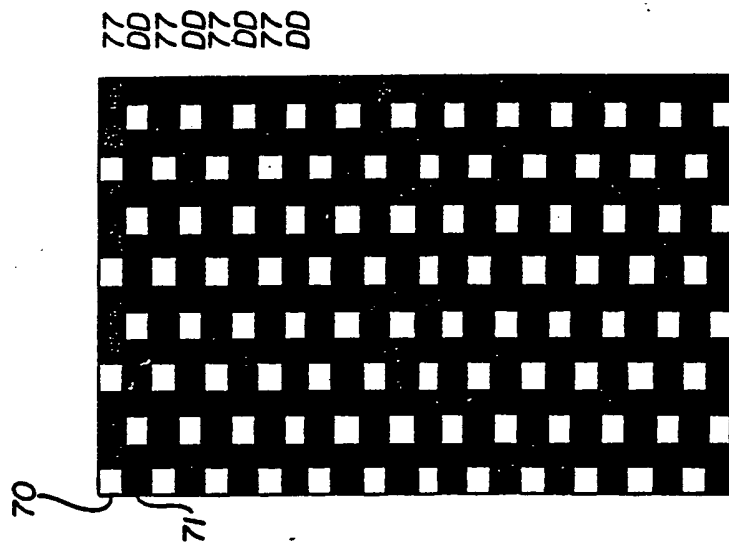


FIG-8

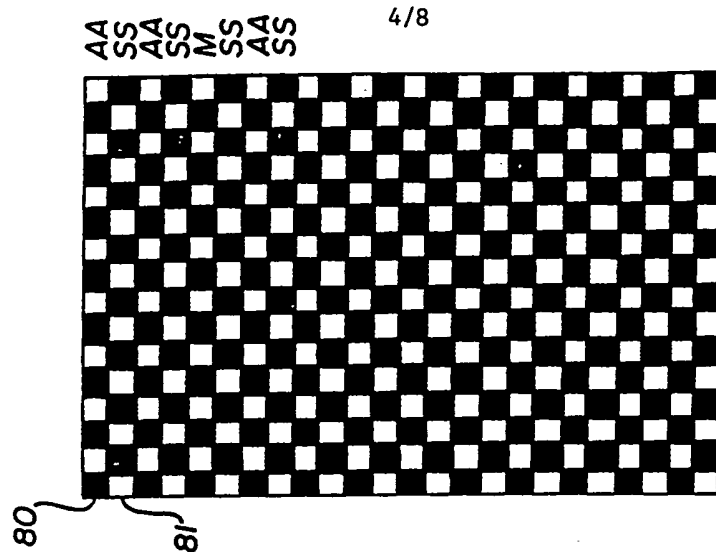


FIG-9

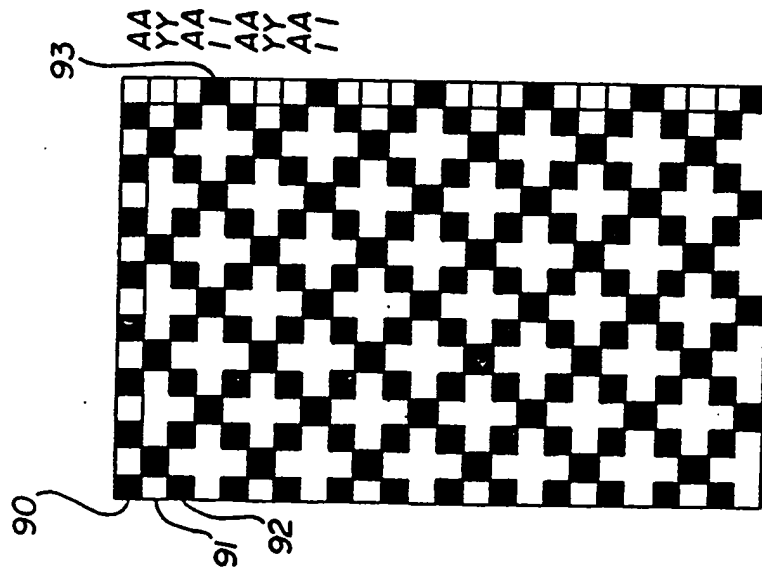


FIG-10

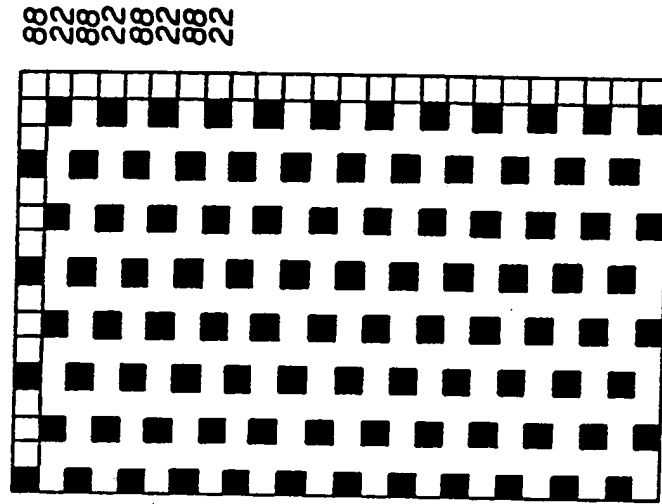


FIG-11

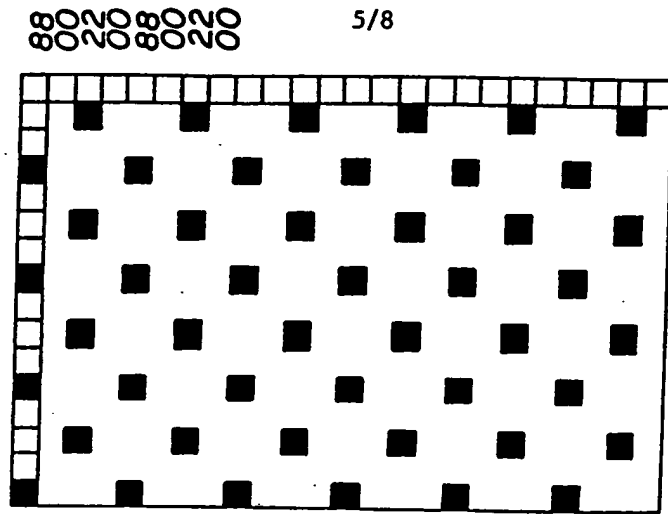


FIG-12

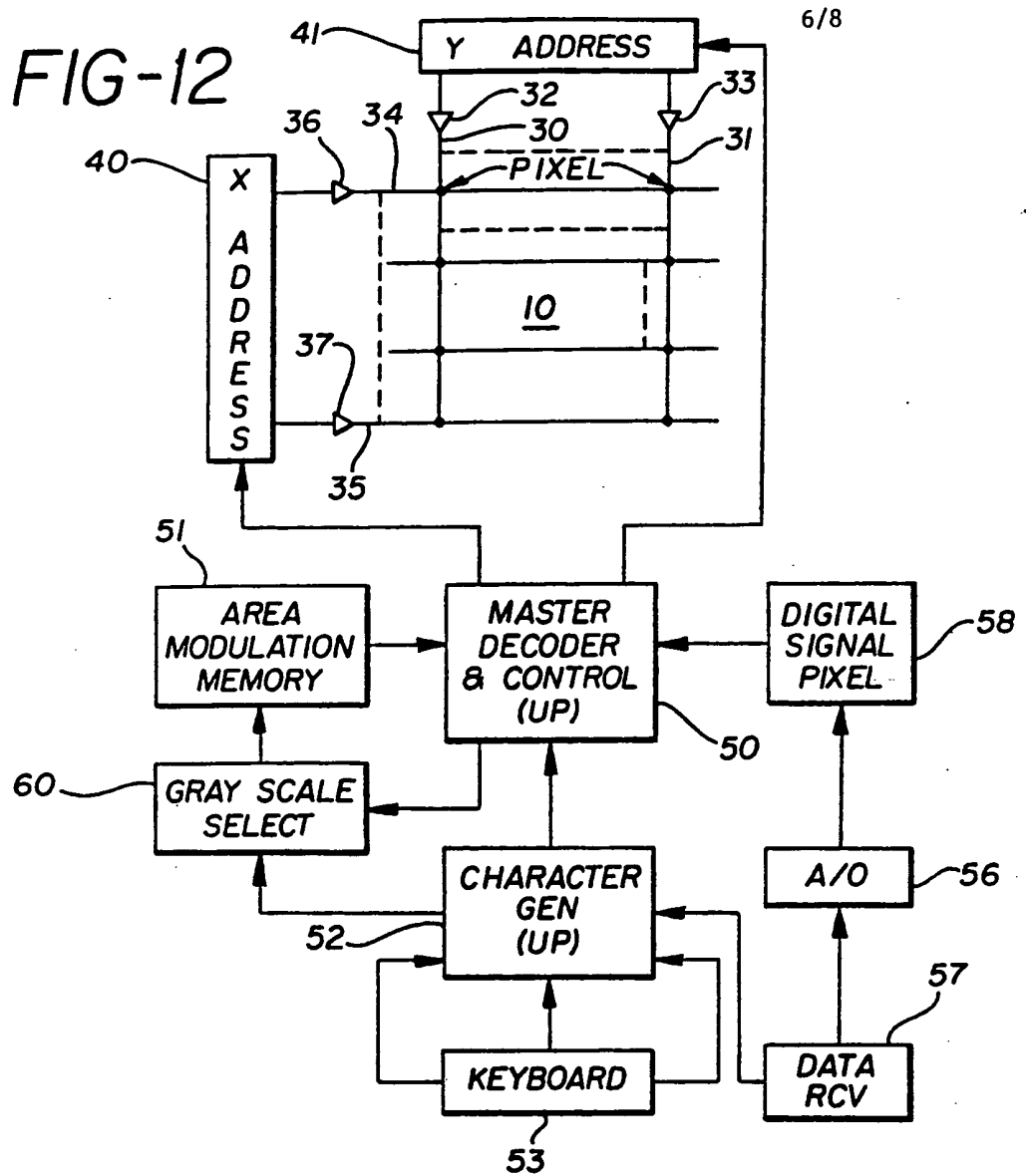


FIG-13

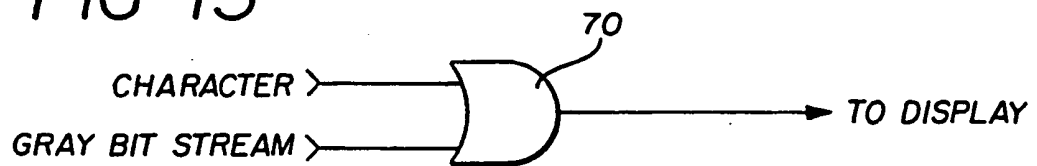
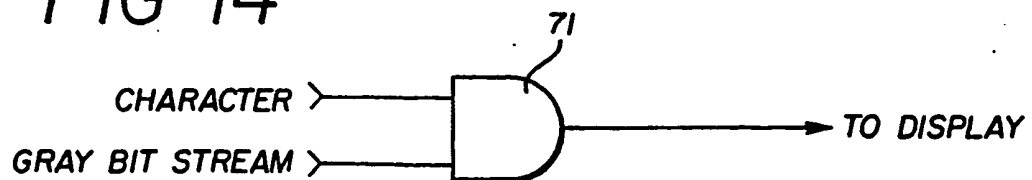
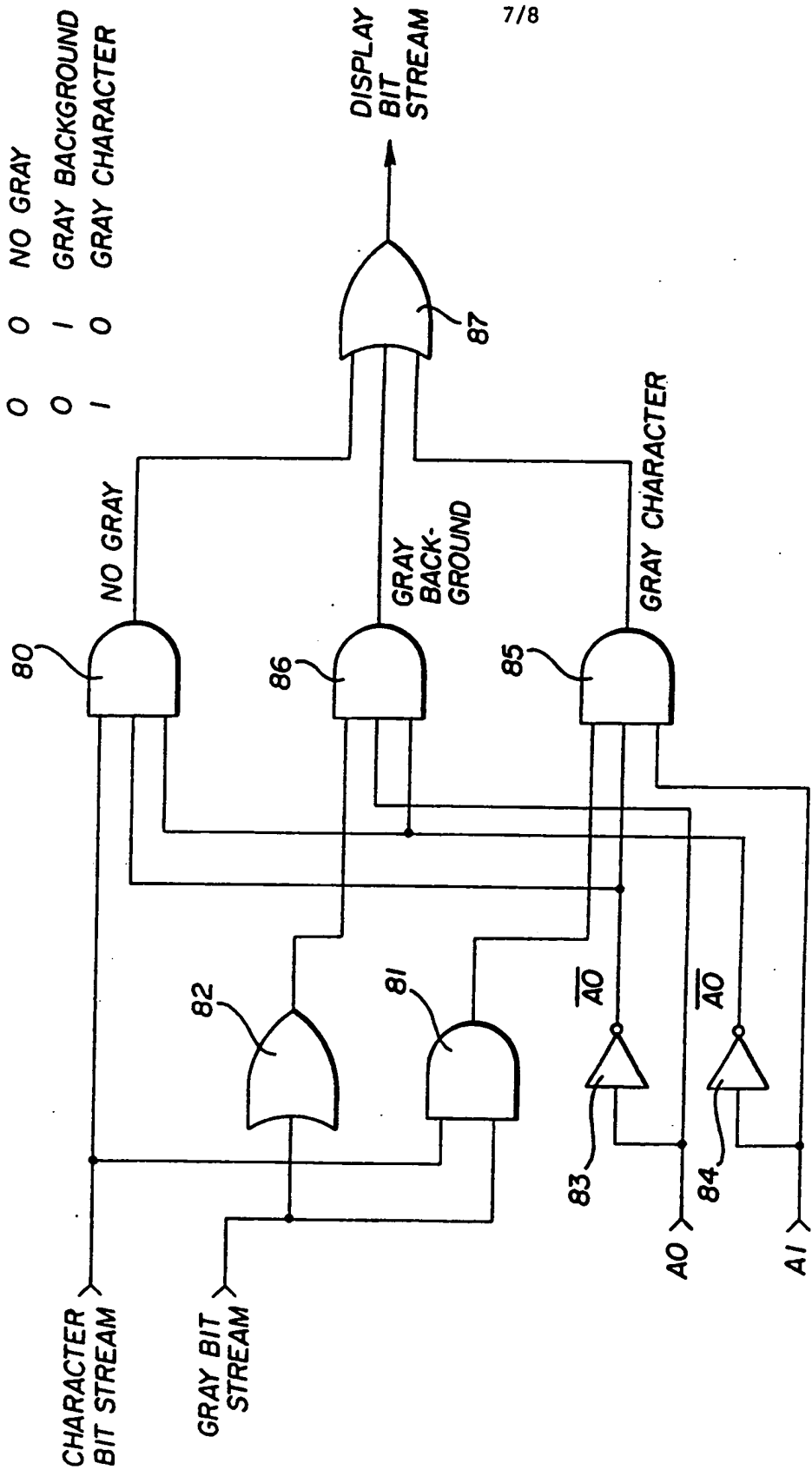


FIG-14



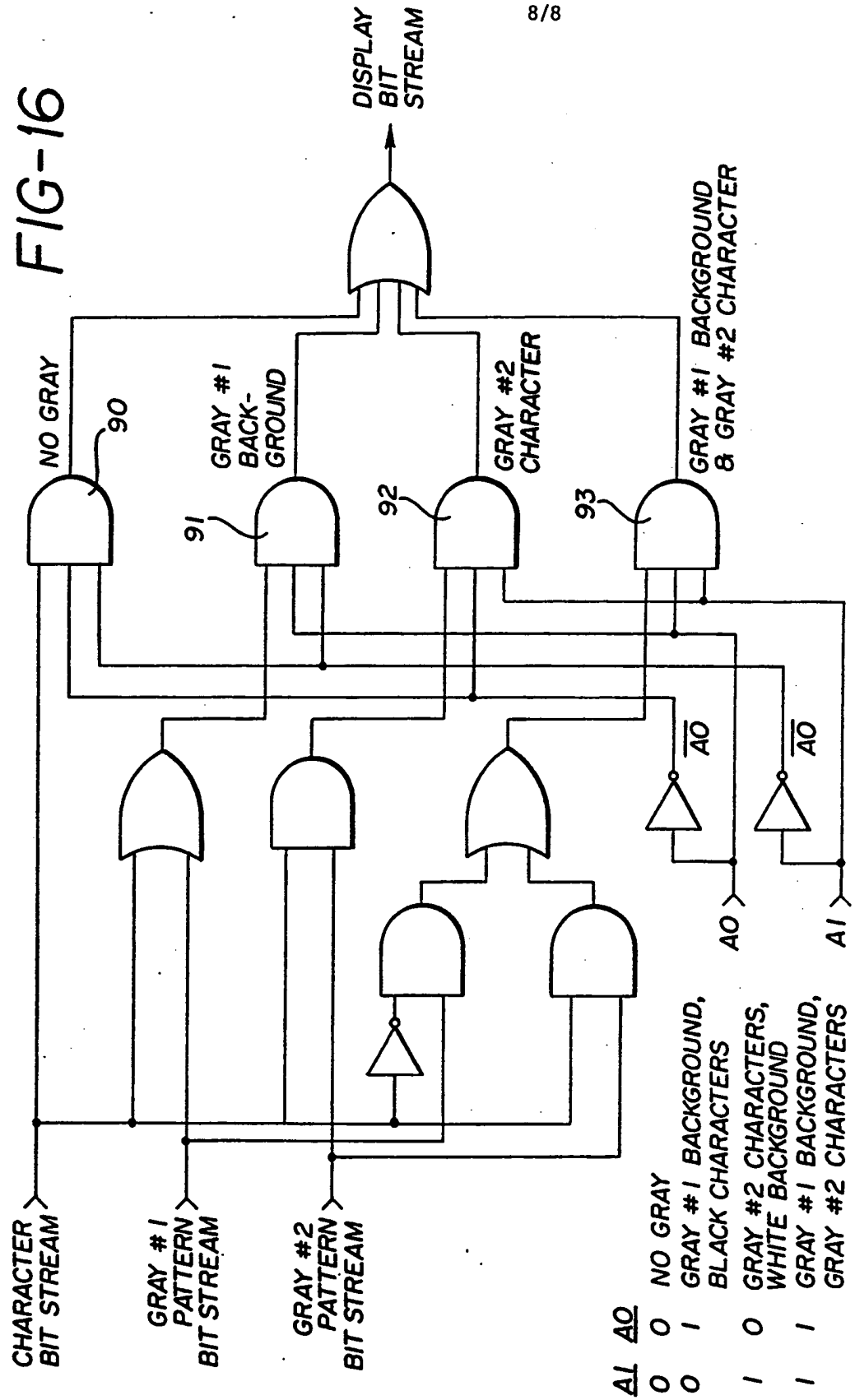
7/8

FIG-15



<u>AI</u>	<u>AO</u>	
0	0	NO GRAY
0	1	GRAY BACKGROUND
1	0	GRAY CHARACTER

FIG-16



# INTERNATIONAL SEARCH REPORT

International Application No. **PCT/US91/04834**

## I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) <sup>6</sup>

According to International Patent Classification (IPC) or to both National Classification and IPC  
**IPC (5): G09G 3/34**  
**U.S.Cl.: 340/787**

## II. FIELDS SEARCHED

Minimum Documentation Searched <sup>7</sup>

Classification System

Classification Symbols

U.S.

**340/787,767,793,703; 358/236,230,429  
382/50,54**

Documentation Searched other than Minimum Documentation  
to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>

## III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup>

Category <sup>1</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
Y	US, A, 4,833,464 (DISANTO ET AL.) 23 May 1989 See the entire document.	1-14
Y	US, A, 4,688,031 (HAGGERTY) 18 August 1987 See the entire document.	1-14
Y	Patent Abstracts of Japan, publication number 63287828, issued 17 March 1989, "Liquid Crystal Display Controller" (TSUGUJI).	1,2,5-12

### \* Special categories of cited documents: <sup>10</sup>

- "A" document defining the general state of the art which is not considered to be of particular relevance
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## IV. CERTIFICATION

Date of the Actual Completion of the International Search

**20 February 1992**

Date of Mailing of this International Search Report

**18 MAR 1992**

International Searching Authority

**ISA/US**

Signature of Authorized Officer

**For Mike Fatahiyar** *[Signature]*

**INTERNATIONAL DIVISION**

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International Bureau

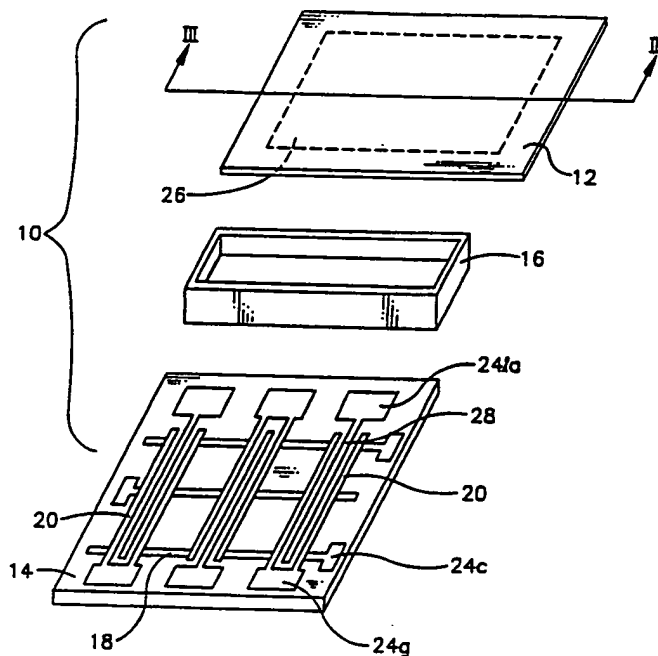


B51

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>5</sup> :  G09G 3/34	A1	(11) International Publication Number: WO 93/04459 (43) International Publication Date: 4 March 1993 (04.03.93)
(21) International Application Number: PCT/US92/06877 (22) International Filing Date: 17 August 1992 (17.08.92) (30) Priority data: 746,854 19 August 1991 (19.08.91) US (71) Applicant: COPYTELE, INC. [US/US]; 900 Walt Whitman Road, Huntington Station, NY 11746 (US). (72) Inventors: DISANTO, Frank, J. ; 27 Par Court, North Hills, NY 11030 (US). KRUSOS, Denis, A. ; 1 Lloyd Harbor Road, Lloyd Harbor, NY 11743 (US). SCHUBERT, Frederic, E. ; 18 Cordwood Path, Shoreham, NY 11786 (US).		(74) Agent: PLEVY, Arthur, L.; P.O. Box 1366, 146 Route 1 North, Edison, NJ 08818-1366 (US). (81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE). Published <i>With international search report.  Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: ELECTROPHORETIC DISPLAY PANEL WITH INTERLEAVED LOCAL ANODE



(57) Abstract

An improvement to an electrophoretic display having a cathode/grid/local anode matrix (18, 20, 28) and a remote anode (26) and to the method for making the display includes forming the local anode lines (28) in the same plane as the grid lines (20) from the same material and in the same fabricating step. The local anode lines (28) are insulated from the grid lines (20) and are interleaved therewith, each being formed on a common layer of photoresist. It is preferred that each grid line be associated with one local anode line, that the grid lines (20) have tines (30) and that the local anode lines (28) be disposed between the tines (30).

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**ELECTROPHORETIC DISPLAY PANEL  
WITH INTERLEAVED LOCAL ANODE**

**Technical Field of the Invention**

The present invention relates to an electrophoretic display panel apparatus and methods for making same and, more particularly, to electrophoretic display panels with a local anode having elements which are interleaved with the grid elements of the display for assisting in the control of pigment particle migration and position.

**Background Art**

Electrophoretic displays (EPIDS) are now well known. A variety of display types and features are taught in several patents issued in the names of the inventors herein, Frank J. DiSanto and Denis A. Krusos and assigned to the assignee herein, Copytele, Inc. of Huntington Station, New York. For example, U.S. Patent Nos. 4,655,897 and 4,732,830, each entitled ELECTROPHORETIC DISPLAY PANELS AND ASSOCIATED METHODS describe the basic operation and construction of an electrophoretic display. U.S. Patent No. 4,742,345, entitled ELECTROPHORETIC DISPLAY PANELS AND METHODS THEREFOR, describes a display having improved alignment and contrast. Many other patents regarding such displays are also assigned to Copytele, Inc. One pending patent application which may have some relevance to the present invention is Application No. 07/345,825 entitled DUAL ANODE FLAT PANEL ELECTROPHORETIC DISPLAY APPARATUS, each of which shall be described below.

The display panels shown in the above-mentioned patents operate upon the same basic principle, viz., if a suspension of electrically charged pigment particles in a dielectric fluid is subjected to an applied electrostatic field, the pigment particles will migrate through the fluid in response to the electrostatic field. Given a substantially homogeneous suspension of particles having a pigment color different from that of the dielectric fluid, if the applied electrostatic field is localized it will cause a

visually observable localized pigment particle migration. The localized pigment particle migration results either in a localized area of concentration or rarefaction of particles depending upon the sign and direction of the electrostatic field and the charge on the pigment particles. The electrophoretic display apparatus taught in the foregoing U.S. Patents are "triode-type" displays having a plurality of independent, parallel, cathode row conductor elements or "lines" deposited in the horizontal on one surface of a glass viewing screen. A layer of insulating photoresist material deposited over the cathode elements and photoetched down to the cathode elements to yield a plurality of insulator strips positioned at right angles to the cathode elements, forms the substrate for a plurality of independent, parallel column or grid conductor elements or "lines" running in the vertical direction. A glass cap member forms a fluid-tight seal with the viewing window along the cap's peripheral edge for containing the fluid suspension and also acts as a substrate for an anode plate deposited on the interior flat surface of the cap. When the cap is in place, the anode surface is in spaced parallel relation to both the cathode elements and the grid elements. Given a specific particulate suspension, the sign of the electrostatic charge which will attract and repel the pigment particles will be known. The cathode element voltage, the anode voltage, and the grid element voltage can then be ascertained such that when a particular voltage is applied to the cathode and another voltage is applied to the grid, the area proximate their intersection will assume a net charge sufficient to attract or repel pigment particles in suspension in the dielectric fluid. Since numerous cathode and grid lines are employed, there are numerous discrete intersection points which can be controlled by varying the voltage on the cathode and grid elements to cause localized visible regions of pigment concentration and rarefaction. Essentially then, the operating voltages on both cathode and grid must be able to assume at least two states corresponding to a logical one and a logical zero. Logical one for the cathode may either correspond to attraction or repulsion of pigment. Typically, the cathode and grid voltages are selected such that only

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when both are a logical one at a particular intersection point, will a sufficient electrostatic field be present at the intersection relative to the anode to cause the writing of a visual bit of information on the display through migration of pigment particles. The bit may be erased, e.g., upon a reversal of polarity and a logical zero-zero state occurring at the intersection coordinated with an erase voltage gradient between anode and cathode. In this manner, digitized data can be displayed on the electrophoretic display.

6 An alternative EPID construction is described in Application No. 07/345,825, referred to above, which relates to an electrophoretic display in which the cathode/grid matrix as is found in triode-type displays is overlaid by a plurality of independent separately addressable "local" anode lines. The local anode lines are deposited upon and align with the grid lines and are insulated therefrom by interstitial lines of photoresist. The local anode lines are in addition to the "remote" anode, which is the layer deposited upon the anode faceplate or cap as in triode displays. The dual anode structure aforesaid provides enhanced operation by eliminating unwanted variations in display brightness between frames, increasing the speed of the display and decreasing the anode voltage required during Write and Hold cycles, all as explained in Application No. 07/345,825, which is incorporated herein by reference.

12 An examination of Application No. 07/345,825 reveals that the local anode structure employed therein is realized by applying a layer of photoresist over the grid elements, which are formed from a first metal, such as, chrome. A layer of a second metal, e.g., nickel or aluminum, is applied over the photoresist layer. Yet another layer of photoresist is applied over the second metal layer, and is then masked, exposed and developed in the same form as the grid elements. The second metal layer is then etched with a suitable solution. The photoresist between the first and second metal layers is then plasma etched. A layer of SiO<sub>2</sub> is then deposited over the resulting structure.

It is an object of the present invention to provide an alternative structure and method for making the remote anode/cathode/grid matrix than that shown in Application No. 07/345,825.

#### Disclosure of the Invention

6           The problems and disadvantages associated with conventional electrophoretic displays are overcome by the present invention which includes in an electrophoretic display of the type having: a cathode matrix comprising a plurality of parallel lines arranged in a given direction, a grid matrix insulated from the cathode matrix and comprising a plurality of parallel lines each perpendicular to the cathode lines to form an X-Y addressing matrix, and  
12           a conventional anode electrode separated from the X-Y matrix, the space between the anode electrode and the X-Y matrix accommodating an electrophoretic dispersion including pigment particles suspended in a fluid; the improvement therewith of an additional anode electrode comprising a plurality of parallel lines each associated with and insulated from the grid lines. The additional anode electrode is disposed within a plane shared by the grid matrix  
18           and operates to control the path of the pigment particles to and from the X-Y matrix and to allow excess pigment to remain at the conventional anode electrode.

#### Brief Description of the Drawings

24           For a better understanding of the present invention, reference is made to the following detailed description of an exemplary embodiment considered in conjunction with the accompanying drawings, in which:

FIG. 1 is an exploded perspective view of an electrophoretic display in accordance with an exemplary embodiment of the present invention.

30           FIG. 2 is an enlarged plan view of a selected local anode element interleaved with a selected grid element in accordance with an exemplary embodiment of the present invention and as shown in FIG. 1.

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FIG.3 is a cross-sectional view of the electrophoretic display shown in FIG. 1 in the unexploded state, taken along section line III-III and looking in the direction of the arrows.

FIG. 4 is an enlarged plan view of a selected grid and/or local anode element structure as is taught in prior Application No. 07/345,825 filed by the inventors herein.

FIG.5 is a cross-sectional fragmentary view of an electrophoretic display in accordance with Application No. 07/345,825 and which incorporates the element structure shown in FIG. 4.

#### Best Mode for Carrying Out the Invention

FIG. 1 shows an electrophoretic display 10 in accordance with the present invention. The display 10 has an anode faceplate 12 and a cathode faceplate 14 which are sealably affixed on either side of an interstitial spacer 16 to form a fluid-tight envelope for containing a dielectric/pigment particle suspension or electrophoretic fluid (not shown). The faceplates 12 and 14 are typically flat glass plates upon which are deposited conductor elements to comprise the situs of electrostatic charge for inducing motion in the electrophoretic fluid. The techniques, materials and dimensions used to form the conductor elements upon the faceplates and the methods for making EPIDS, in general, are shown in U.S. Patent Nos. 4,655,897, 4,732,830 and 4,742,345 which patents are incorporated herein by reference.

In the invention, as depicted in FIG. 1, for example, a plurality of independent, electrically conductive cathode lines 18, shown here as horizontal rows, are deposited upon the cathode faceplate 14 using conventional deposition and etching techniques. Of course, the orientation of the cathode lines depends upon the orientation of the screen, which, if rotated 90 degrees, would position the cathode lines vertically, thus, the cathode lines are arbitrarily defined as horizontal. It is preferred that the cathode elements 18 be composed of Indium Tin Oxide (ITO) as set forth in U.S. Patent No.

4,742,345. A plurality of independent grid conductor lines 20 are superposed in the vertical over the cathode elements 18, i.e., at right angles thereto, and are insulated therefrom by an interstitial photoresist layer 22 (see FIG. 2). The grid elements 20 may be formed by coating the photoresist layer 22 with a metal, such as nickel, using sputtering techniques or the like, and then selectively masking and etching to yield the intersecting but insulated configuration shown in FIG. 1. Each cathode and grid element 18, 20 terminates at one end in a contact pad 24c and 24g, respectively, or is otherwise adapted to permit connection to display driver circuitry (not shown). An anode 26 is formed on an interior surface of the anode faceplate 12 by plating with a thin layer of conductor material, such as, chrome.

Whereas the foregoing components have been previously described in prior patents and applications of the present Applicants, the present invention includes a novel local anode 28 structure. As stated above, the benefits and operation of an EPID having a local anode have been recognized and described in Application No. 07/345,825 by the present Applicants. Previously, however, the local anode lines have been formed superposed over and in alignment with the grid elements, and separated therefrom by an interstitial layer of photoresist insulation (see FIG. 5). In the present invention, the local anode 28 lines are formed at the same time, of the same material and in the same plane as the grid elements 20. This is accomplished by interleaving the local anode 28 and grid 20 elements. Thus, the mask that was used to form the plurality of grid lines has been altered such that a plurality of grid lines and a plurality of local anode lines are simultaneously formed by a single mask. After formation, a SiO<sub>2</sub> coating can be applied over the grid/local anode/cathode complex as set forth in Application No. 07/345,825. The display is also operated in the same fashion as in that application.

FIG. 2 shows an exemplary configuration for a single grid line 20, a single local anode line 28 and their interleaving. As has been recognized

previously, the configuration of the grid lines as a tined element, i.e., a element having a plurality of coextensive parallel forks 30 emanating from a common area, here the grid contact pad 24g, improves display brightness as described in U.S. Patent No. 4,742,345. In the embodiment shown in FIG. 2, the local anode 28 is depicted as having a single elongated portion 32 emanating from a contact pad portion 24la. The elongated portion 32 of the local anode 28 extends between the forks 30 of the grid line 20, and, in this sense, interleaves with the grid line 20. It should be noted that the local anode 28 could also be provided with forks like those of the grid line 20, and in that event, the interleaving could be in the form of alternating grid and local anode forks. Indeed, any number of grid forks 30 (elongated portions) and local anode forks or elongated portions 32 could be employed. It is required, however, that they be insulated one from another, and, in order to provide a regular coordinate grid along with the cathode lines 18, should be substantially parallel to each other and perpendicular to the cathode lines 18. It is preferred that the local anode line 28 as shown in FIG. 2 have a width of approximately 30 microns, that a spacing of 12 microns separate the elongated portion 32 of the local anode 28 from the forks 30 of the grid line 20, and that the grid forks 30 be approximately 10 microns wide with an inter-fork spacing of 12 microns. These dimensions provide a local anode 28 which is wider than the grid forks 30 and which allows better pigment hiding than if the local anode were narrower. Overall, the interleaved grid and local anode elements configured according to these dimensions have an open area to closed area ratio of approximately 40%, which is within the range of normal triode EPIDS and a screen produced in accordance with these dimensions has a normal display brightness. Open area ration should be in the range of 30% to 60% for adequate screen brightness.

To form an EPID 10 like that shown in FIG. 1, the parts may assembled in a stack and placed in an oven for baking. The spacer 16, in that case, would be coated on surfaces which contact adjacent elements with a material which would become plastic at baking temperatures, such as, epoxy.

Upon baking, the meltable material flows and the elements form a laminate upon cooling. Of course, other methods exist within the scope of the normally skilled artisan for assembling the elements of the EPID 10 shown, such as, e.g., gluing. The lamination of the EPID elements forms an envelope for containing the dielectric fluid/pigment particle suspension.

6                   FIG. 3 shows the electrophoretic display of FIG. 1 utilizing the interleaving configuration shown in FIG. 2 assembled and in cross-section. The anode 26 in the embodiment shown, is a plate-like area of conductor material having a length and width essentially matching that of the cathode/grid/local anode matrix, i.e., coextensive with the matrix, as is taught in the above  
12                   referenced patents and applications of the present Applicant. Unlike previous teachings, the present invention has the local anode 28 elements deposited upon photoresist layer 22 in the same plane and by the same manufacturing step as the grid elements 20 (the individual forks 30 being shown in cross-section). Since all conductor elements are quite thin, they extend  
18                   beneath the interstitial spacer 16 without special provision and at least one end thereof provides a terminal exterior to the envelope for connecting display driver circuitry (not shown).

                  The proportions of the grid and local anode lines as shown in FIGS. 1-3 have been distorted for the purposes of illustration, viz., the elongated portions would be long enough to extend substantially the entire height of the cathode faceplate 14, whereas the width of the individual lines would be small enough to accommodate in the order of 2,200 lines on an 8" X  
24                   10" screen. Thus, in real displays the grid and anode lines are very thin and elongated. A workable panel would have a large number of intersections, e.g., 2,200 X 1,700 or a total of 3,740,000 separately addressable intersection points. For ease of illustration, only a few cathode lines 18, grid lines 20, and local anode lines 28 are depicted. More illustrations of electrophoretic displays, their components and electrical circuitry can be seen by referring to U.S.

Patents Nos. 4,742,345 and 4,772,820, each being awarded to the inventors herein and which are incorporated by reference herein.

FIGS. 4 and 5, are illustrations of certain features of EPIDS disclosed by the Applicants herein in Application No.07/345,825 and are included for the purpose of providing a comparison to the present invention.

6 Elements having essentially the same form and function as corresponding elements in the present invention are labelled with the same reference numerals. Common elements in the prior EPIDS which have been altered in the present invention are flagged by the suffix "pa". FIG. 4 illustrates the configuration for a tined grid (and local anode) element 20pa previously disclosed in Application No.07/345,825. On comparison to the grid element  
12 20 configuration taught by the present invention, it should be observed that, while the tined configuration is retained, a spacing must be provided centrally to accommodate the interleaved anode line.

FIG. 5 illustrates the stacking of the local anode elements 28pa upon the grid elements 20pa previously used by the applicants in EPIDS having a remote and a local anode. It should be appreciated that this stacking  
18 configuration is done in several steps and that the local anode 28pa must be closely aligned with the grid elements 20pa for effective operation. The present invention has neither of these requirements. Another difference between the present invention and that shown in FIG. 5 is that the local anode 28 of the present invention alters the distribution of pigment particles in the plane of the grid and the local anode. In contrast, in the device shown in FIG.  
24 5, the local anode effects pigment concentration at the grid by drawing it into a plane removed from the grid.

It should be understood that the embodiments described herein are merely exemplary and that a person skilled in the art may make many variations and modifications without departing from the spirit and scope of the invention as defined in the appended claims.

## I/We Claim:

1. In an electrophoretic display of the type having a cathode matrix comprising a plurality of parallel lines arranged in a given direction, with a grid matrix insulated from said cathode matrix and comprising a plurality of parallel lines each perpendicular to said cathode lines to form an X-Y addressing matrix with a conventional anode electrode separated from said X-Y matrix with the space between said anode electrode and said X-Y matrix accommodating an electrophoretic dispersion including pigment particles suspended in a fluid, the improvement therewith of:

an additional anode electrode comprising a plurality of parallel lines each associated with and insulated from said grid lines, said additional anode electrode disposed within a plane shared by said grid matrix and operative to control the path of said pigment particles to and from said X-Y matrix and to allow excess pigment to remain at said conventional anode electrode.

2. The display of Claim 1, wherein said additional anode lines are distributed in said plane and between said grid lines in a predetermined repeating pattern.

3. The display of Claim 2, wherein one said grid line is associated with each said additional anode line.

4. The display of Claim 3, wherein each of said grid lines and said additional anode lines have an end for connecting to display driver circuitry and a free end and wherein said connecting ends of each associated grid line and additional anode line are disposed distal to each other.

5. The display of Claim 4, wherein each grid line subdivides distal to said connecting end into at least two tines and said free end of each associated additional anode line inserts between said tines.

6. The display of Claim 5, wherein said at least two tines are four in number and said associated additional anode line is disposed approximately centrally between two sets of two tines of an associated said subdivided grid line.

7. The display of Claim 6, wherein said local anode line is wider than said tines of said grid lines such that said local anode line obscures more pigment particles than said tines.

8. The display of Claim 7, wherein said X-Y matrix and said additional anode matrix together have a combined open area ratio of approximately from 30 to 60%.

9. The display of Claim 1, wherein said additional anode lines and said grid lines are each formed from the same material.

10. An electrophoretic display comprising:

(a) a fluid-tight envelope having a portion thereof which is at least partially transparent;

(b) an electrophoretic fluid contained within said envelope, said fluid having pigmented particles suspended therein;

(c) a plurality of elongated substantially parallel horizontal conductor elements disposed within a first plane and at least partially contained within said envelope;

6 (d) a first plurality of elongated substantially parallel vertical conductor elements at least partially contained within said envelope electrically insulated from said horizontal elements and disposed within a second plane, said first and said second planes being substantially parallel and in proximity to each other, said plurality of horizontal elements and said plurality of vertical elements forming a matrix with a plurality of intersections when viewed along a line perpendicular to said first and said second planes;

(e) a second plurality of elongated substantially parallel vertical conductor elements at least partially contained within said envelope electrically insulated from said horizontal elements and said first plurality of vertical elements and disposed within said second plane; and

12 (f) a substantially planar conductor member disposed within a third plane proximate and substantially parallel to said second plane and at least partially contained within said envelope, each of said first and second pluralities of vertical elements and said horizontal elements being selectively electrically chargeable to induce movement of said particles within said fluid, said particles being visible through said transparent portion of said envelope.

24 11. The display of Claim 10, wherein said second plurality of vertical elements are distributed in said second plane interleaved between said first plurality of elements in a repeating pattern and wherein each element of said first plurality is associated with a corresponding element of said second plurality.

12. The display of Claim 11, wherein said first and second pluralities of elements are each supported upon a layer of photoresist.

6 13. The display of Claim 12, wherein each of said first and second pluralities of elements have an end for connecting to display driver circuitry and a free end, said connecting ends of each of said first plurality of elements being disposed distal to said connecting end of a corresponding element of said second plurality of elements, wherein each element of said first plurality of elements subdivides distal to said connecting end into at least two tines and said free end of a corresponding element of said second plurality of elements inserts between said tines.

12 14. The display of Claim 13, wherein said first and said second plurality of elements are each formed from chromium.

15. The display of Claim 13, wherein said first and said second plurality of elements are each formed from aluminum.

18 16. The display of Claim 13, wherein said display is a tetrode-type display, said plurality of horizontal elements being the cathode, said first plurality of vertical elements being the grid, said second plurality of vertical elements being the local anode and said planar member being the remote anode.

24 17. A method for fabricating the cathode/grid/local anode matrix on the cathode faceplate of a dual anode electrophoretic display comprises performing, in substantially the order shown, the steps of:

- (a) forming a plurality of cathode lines on said cathode faceplate;
  - (b) depositing a first layer of photoresist over said cathode lines;
  - (c) coating said first layer of photoresist with a conductor material;
- 30

- of photoresist;
- (d) coating said conductor material with a second layer
- (e) masking said second layer of photoresist with a mask corresponding to the shape of a plurality of grid lines interleaved with a plurality of local anode lines;
- 6 (f) exposing said second layer of photoresist through said mask;
- (g) developing said second layer of photoresist;
- (h) acid etching said conductor material coating where not covered by said second layer of photoresist remaining after developing; and
- 12 (i) plasma etching said first and said second layers of photoresist where not covered by said conductor material remaining after said step of acid etching.

18 18. The method of Claim 17, further including the step of applying a SiO<sub>2</sub> coating over said cathode/grid/local anode matrix after said step of plasma etching.

19. The method of Claim 18, wherein said step of coating with a conductor material includes sputtering a layer of chrome upon said first layer of photoresist.

24 20. The method of Claim 18, wherein said step of coating with a conductor material includes sputtering a layer of aluminum upon said first layer of photoresist.

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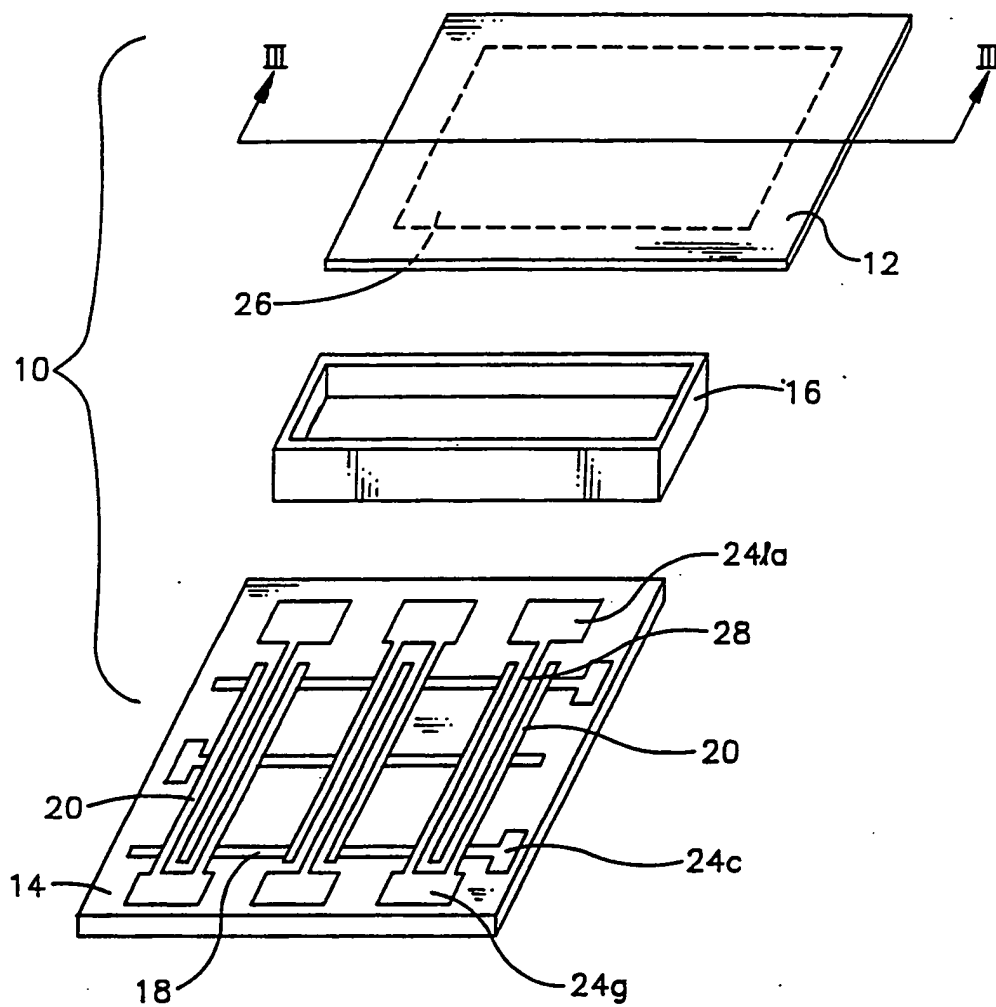


FIG. 1

SUBSTITUTE SHEET

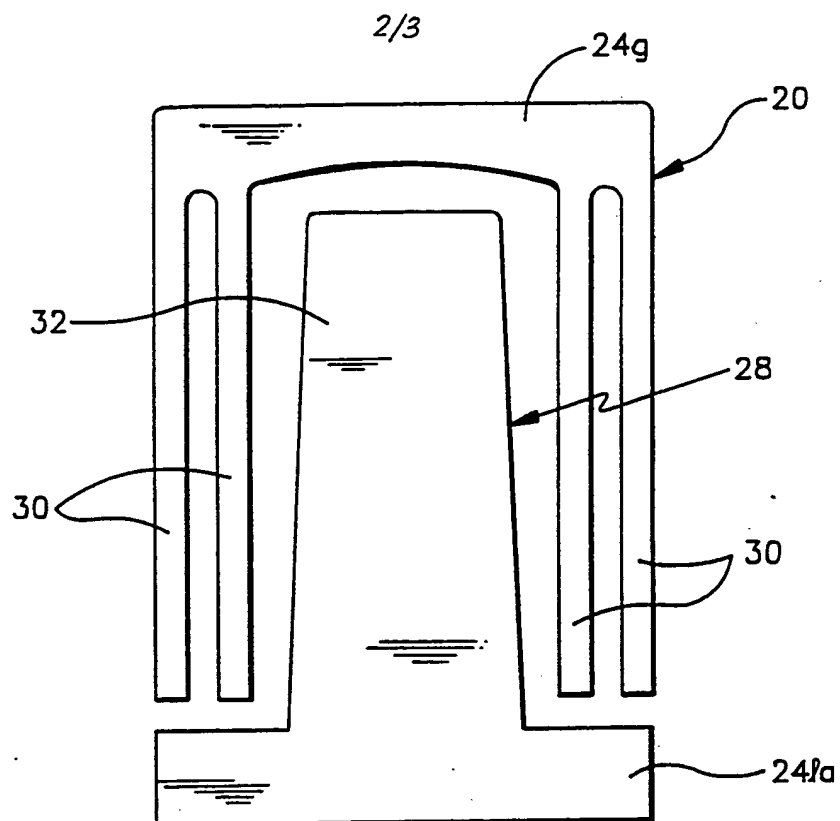


FIG. 2

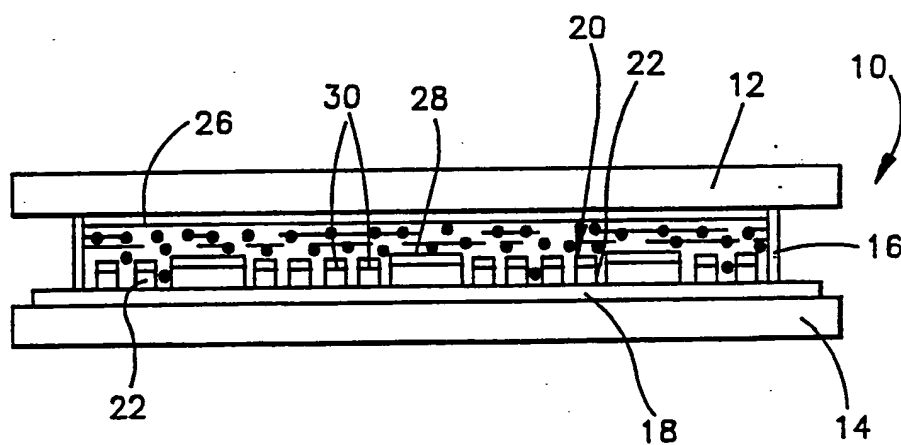


FIG. 3

SUBSTITUTE SHEET

3/3

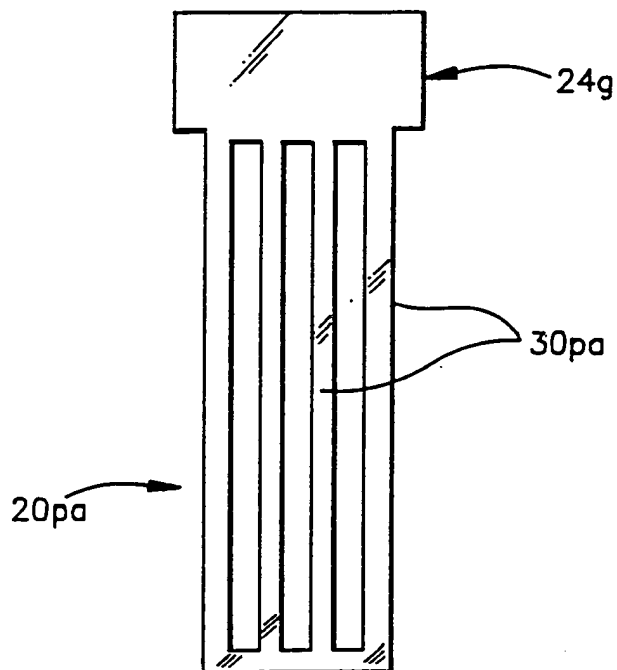


FIG. 4

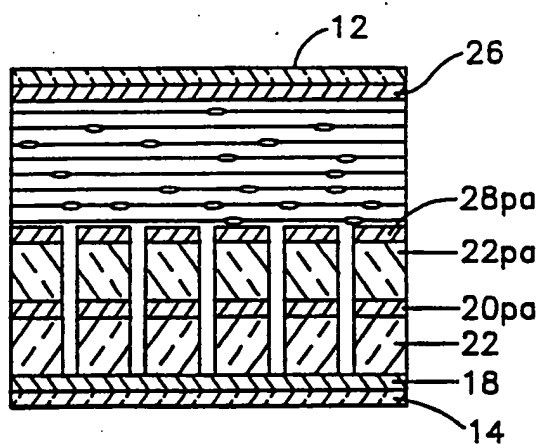


FIG. 5

SUBSTITUTE SHEET

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US92/06877

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G09G 3/34  
US CL :340/787

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 340/787,788; 204/299R; 428/1; 359/296

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS (electrophoretic, display, additional anode)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X/Y,P Y A,P A	US, A, 5,053,763 (DiSanto) 01 October 1991 see entire document US, A, 4,686,524 (White) 11 August 1987 Figure 2 US, A, 5,077,157 (DiSanto) 31 December 1991 see entire document US, A, 4,742,345 (DiSanto) 03 May 1988 Figures 1 and 4	1-3,10,17-20/1-20 1-20 1,10,17 1,10,17

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:	* T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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16 DECEMBER 1992

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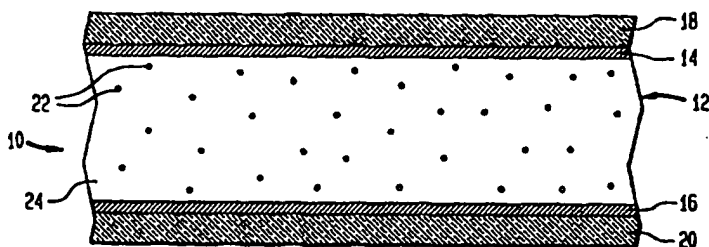


B52

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/US94/03813 (22) International Filing Date: 7 April 1994 (07.04.94) (30) Priority Data: 050,840 21 April 1993 (21.04.93) US (71) Applicant: COPYTELE, INC. [US/US]; 900 Walt Whitman Road, Huntington Station, NY 11746 (US). (72) Inventor: HOU, Wei-Hsin; 523 Carlton Avenue, Bethlehem, PA 18015 (US). (74) Agent: PLEVY, Arthur, L.; Plevy &amp; Associates, P.O. Box 1366, 146 Route 1 North, Edison, NJ 08818-1366 (US).</p>		<p>(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report. With amended claims.</p>

(54) Title: BLACK AND WHITE ELECTROPHORETIC PARTICLES AND METHOD OF MANUFACTURE



(57) Abstract

A process for forming dielectric particles (22) includes admixing a first monomer and a crosslinker in a liquid dispersion medium to form a first mixture. A second mixture of an initiator and a stabilizer is prepared and added to the first mixture to form a third mixture in which the first monomer polymerizes to form polymer particles. A second monomer is introduced to the third mixture, the second monomer at least partially polymerizing and grafting upon the previously formed polymer particles. A functional monomer effecting the outer surface charge characteristics of the final particles may be introduced to the third mixture when the second monomer is introduced. The particles (22) may be employed in an electrophoretic fluid (12) for use in an electrophoretic display by dispersing the dielectric particles (22) prepared by the two stage polymerization process in a dielectric fluid (24).

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## BLACK AND WHITE ELECTROPHORETIC PARTICLES AND METHOD OF MANUFACTURE

### TECHNICAL FIELD OF THE INVENTION

5 The present invention relates to dielectric particles and methods for producing same and more particularly to dielectric black and dielectric white particles for use in electrophoretic image displays, electrostatic printing or the like.

### BACKGROUND ART

10 The electrophoretic effect is well known and the prior art is replete with a number of patents and articles which describe the effect. As will be recognized by a person skilled in the art, the electrophoretic effect operates on the principle that certain particles, when suspended in a medium, can be electrically charged and thereby caused to migrate through the medium to an electrode of opposite charge. Electrophoretic image displays (EPIDs) utilize the  
15 electrophoretic effect to produce desired images. In prior art EPIDs, colored dielectric particles are suspended in a fluid medium that is either clear or an optically contrasting color as compared to the dielectric particles. The colored electrophoretic particles are then caused to selectively migrate to, and impinge upon, a transparent screen, thereby displacing the fluid medium against the screen  
20 and creating the desired image.

As will be recognized by a person skilled in the art, the selection of the electrophoretic particles used in the EPID is very important in determining the performance of the EPID and the quality of the viewed image produced. Ideally, electrophoretic particles should all be of a uniform size, to help in  
25 assuring that each of the electrophoretic particles will behave similarly. Additionally, it is desirable to utilize electrophoretic particles that have essentially the same density as the fluid medium in which they are suspended. By using electrophoretic particles of essentially the same density as the suspension medium, the migration of the electrophoretic particles through the medium

remains independent of both the orientation of the EPID and the forces of gravity.

To effect the greatest optical contrast between electrophoretic particles and the suspension medium, it is desirable to have either white particles suspended in a black medium or black particles suspended in a backlighted clear medium. In the prior art, it has been proven difficult to produce black electrophoretic particles that are dielectric, of uniform size and have a density matching that of a common suspension medium. As a result, EPIDs commonly use readily manufactured light colored electrophoretic particles suspended in dark media. Such EPIDs are exemplified in U.S. Patent Nos: 4,655,897 to DiSanto et al., 4,093,534 to Carter et al., 4,298,448 to Muller et al., and 4,285,801 to Chaing. In such prior art, light colored particles are commonly inorganic pigments which have fairly high densities. With the electric field applied, the light colored particles migrate through the grayish suspension producing a light image on a gray background, thereby resulting in an image that is not highly contrasted.

Although titanium dioxide used in EPIDs produces a good optical contrast between the white particles and the suspension medium, it has a density about  $4 \text{ g/cm}^3$  which is too high to be matched with an organic solvent. Sedimentation becomes a problem. In the past decade, great effort has been spent to solve the density problem of titanium dioxide. Coating titanium dioxide particles with a polymeric material to reduce the density of titanium dioxide is an example. Phase separation, direct emulsification, emulsion polymerization and miniemulsion polymerization are the most common techniques used to make the polymer-coated titanium dioxide particles. The uniformity of the coating thickness and the size of final particles made by these methods cannot be well controlled, this causes a large difference in density among final particles, and balancing the density between the final particles and the suspension medium is still a difficult problem.

In application to EPID displays, the properties of the white particles is highly specialized. First, the density of the particles must be low and

uniform in order to be balanced with the suspension medium to prevent sedimentation of the particles. Secondly, the particles must have well controlled surface functionalities for particle charging in dielectric media in order to reach an optimum electrophoretic mobility for electrophoretic imaging. Thirdly, the particles must have suitable crosslinking density as well as particle size and size distribution in order to form good whiteness yielding better optical contrast with the dark medium. Finally, the particles must have good heat and solvent resistance. Conventional techniques of making crosslinked polymer particles are suspension polymerization, emulsion polymerization, miniemulsion polymerization. Unfortunately, the properties of crosslinked polymer particles required in EPID are difficult to obtain by the conventional techniques.

Crosslinked polymer particles prepared by a suspension polymerization technique have wide particle size distribution, e.g. 1-50  $\mu\text{m}$ , which requires classification of the polymer particles. Polymer particles with a narrow particle size distribution can only be obtained at a very low yield. Emulsion polymerization can produce crosslinked polymer particles with a very narrow size distribution, however, it only can produce particle sizes in a sub-micron range (J. Appl. Phys., 26(7), 864 (1955)). In addition, only small amounts of crosslinking monomers can be used, producing particles with poor heat and solvent resistance and poor whiteness. Using the seeded emulsion polymerization technique, crosslinked polymer particles with uniform particle sizes greater than 1  $\mu\text{m}$  can be produced, however, it takes a long time to complete the whole process (Polym. Mater. Sci. Eng. 54, 587 (1986)). On the other hand, miniemulsion polymerization produces (J. Polym. Sci., Polym. Chem. Ed., 17,3069 (1979)) polymer particles having higher crosslinking density, however, the particle size distribution is too broad to obtain uniform electrophoretic mobility resulting in poor electrophoretic images.

It has been reported that it is difficult to produce stable uniform crosslinked polymer particles by a dispersion polymerization method when the

crosslinking monomers is over 1% by weight (J. Polym. Sci., Polym. Chem. Ed., 24, 2995 (1986). Reports are also found for preparing styrene/divinylbenzene particles by batch dispersion co-polymerization and seeded dispersion copolymerization respectively (Colloid Polym. Sci., 269, 217 (1991), however, good monodispersity and heat and solvent resistance still can not be obtained. More recently, Kobayashi and Senna reported production of uniform styrene/divinylbenzene polymer particles with high crosslink density using a dispersion polymerization technique (J. Appl. Polym. Sci., 46,27 (1992)). Although they claimed that the highly crosslinked polymer particles are uniform in size and are greater than 1  $\mu\text{m}$ , no claim was made in regard to controlling of surface functionalities of the final particles, which is so important for particle charging in dielectric media, particularly in EPIDs.

In addition to using white particles suspended in a dark medium to produce contrast images, one may alternatively suspend black particles in a backlighted clear medium. However, as has been mentioned, the development of suitable dielectric black particles remains a goal in the art of electrophoretic image displays. In art other than EPIDs, black particles are commonly produced from carbon. However, carbon blacks are not readily adaptable to EPIDs because carbon blacks are conductive and the density of carbon blacks is not readily matched to a suitable suspension medium. Research efforts have been made in an attempt to solve the density and conductivity problems of carbon blacks, however, none has succeeded without trading off some blackness in the particles created. Such efforts to produce dielectric particles from carbon blacks are exemplified in the following article Hou et al. "Pigmented-Polymer Particles With Controlled Morphologies", (Polymer Latexes, ACS Symposium Series 492, Chap. 25, p. 405, 1992).

### **DISCLOSURE OF THE INVENTION**

The problems and disadvantages associated with conventional dielectric particles and methods for making same are overcome by the present invention which includes a process for forming dielectric particles in which a first monomer is polymerized in a dispersion medium to form particles. A second monomer is then polymerized in the

same medium and grafts upon the previously formed particles. The surface functionality of the particles is controlled. The particles may be employed in an electrophoretic fluid for use in an electrophoretic display by dispersing the dielectric particles prepared by the two stage polymerization process in a dielectric fluid.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a diagrammatic, cross-sectional view of an EPID having particles in accordance with a first embodiment of the present invention.

FIG. 2 is a diagrammatic cross-sectional view of an alternative EPID construction having particles in accordance with a second embodiment of the present invention.

### **BEST MODE FOR CARRYING OUT THE INVENTION**

The present invention uses a two-stage dispersion polymerization technique to produce highly crosslinked polymer particles with whiteness sufficient for good image contrast in dark suspension media and which have a density close to 1 g/cm<sup>3</sup>. The particles can be used as white electrophoretic particles (instead of titanium dioxide) in EPIDs and have uniform size and low density and are easy to balance with the density of many organic solvents.

Particles in accordance with the present invention have specialized surface functionalities which permit control of particle charging in dielectric

media to produce an optimum electrophoretic mobility, which, with controlled particle size, size distribution and crosslinking density, permit production of high quality electrophoretic images.

5 The present invention may also be employed to produce black electrophoretic particles which do not use carbon black. Rather, highly crosslinked polymer particles stained with a metal oxide are used to form dielectric black particles suitable for use in an EPID. More particularly, the preferred embodiment of the present invention uses a two-stage dispersion polymerization technique to produce highly crosslinked polymer particles which  
10 are further reacted with a metal oxide to form dielectric black particles with good blackness. These particles yield good image contrast in a backlighted clear medium, have uniform size and low density which make them easy to density match with any organic solvents, and have specialized surface functionalities which allow control of particle charging in dielectric media to produce optimum  
15 electrophoretic mobility.

Although the present invention black and white particles can be used in many different applications where particles of high blackness or whiteness and low density are desired, such as coating, printing ink and electrostatic printing, they are especially suitable for use in connection with  
20 electrophoretic image displays (EPIDs). Accordingly, the present invention black and white dielectric particles will be described in connection with typical EPIDs.

Referring to Fig. 1, there is shown a cross sectional view of a segment of a simple electrophoretic image display 10, magnified to show a single pixel (intersection). As will be recognized by a person skilled in the art, an EPID  
25 may contain a volume of an electrophoretic dispersion 12 disposed between an anode 14 and a cathode 16. The anode 14 and cathode 16 are deposited upon glass plates 18, 20 in the form of a thin layer of indium-tin-oxide (ITO) or a like compound. The ITO layer is deposited in such a manner as to be substantially transparent when viewed through the glass plates 16, 18.

In accordance with a first embodiment of the present invention, the electrophoretic dispersion 12 is comprised of white dielectric electrophoretic particles 22 suspended in a dark color medium 24. The electrophoretic particles 22 have a density substantially equivalent to that of the fluid medium 24 so as to remain randomly disperse in the fluid medium 24, unaffected by the orientation of the EPID or the effects of gravity. When a sufficient electrical bias is applied between the anode 14 and cathode 16, the electrophoretic particles 22 migrate in response thereto to either the cathode 16 or anode 14 depending on polarity and displace the dark color medium 24 adjacent to the ITO layer, thereby creating a white pixel. Reversing the voltage produces a dark pixel.

Figure 2 shows in cross section a pixel of another type of EPID 110 wherein electrophoretic dielectric particles are employed in the manner of a shutter. As will be recognized by a person skilled in the art, an EPID of this type contains a volume of an electrophoretic dispersion 112 disposed between an anode 114 and a cathode 116 as in FIG. 1. A conductive mesh 126 is disposed in the fluid 112 between the cathode 116 and anode 114.

In accordance with a second embodiment of the present invention, the electrophoretic dispersion 112 is comprised of black dielectric electrophoretic particles 122 suspended in clear medium 124. The electrophoretic particles 122 have a density substantially equivalent to that of the fluid medium 124 so as to remain randomly disperse in the fluid medium 124, unaffected by the orientation of the EPID or the effects of gravity. When the cathode 116, anode 114 and the mesh 126 are properly biased, the electrophoretic particles 122 may be made to migrate to cathode 116 displacing the clear medium 124 adjacent to the ITO layer, thereby blocking the light produced by the light source 128. Alternately, the electrodes may be biased so that the particles 122 cling to the mesh and do not block light from source 128. The displayed pixel is therefore black or white depending on the voltage settings.

As noted previously, the production of a white image on a dark

color background or a black image on a light background is highly desirable. However, a major obstacle to such a combination has been the lack of dielectric black and white particles that have good hiding power and also a density that can be readily matched with common suspension fluids. The present invention black electrophoretic particles 122 and white electrophoretic particles 22 are formed from crosslinked polymer particles using two stage dispersion polymerization techniques with and without staining with a metal oxide respectively. In general, the polymeric materials are dielectric and have densities close to  $1 \text{ g/cm}^3$ , thus the final electrophoretic particles are non-conductive and can easily be matched with many common EPID suspension fluids without any sedimentation problem. Since the electrophoretic particles are highly crosslinked polymer particles, they have excellent heat and solvent resistance and can be used in a wide range of organic solvents, even at high temperatures during cell sampling. In addition, the particle size, size distribution and surface functionalities of the final particles can be precisely controlled during the second-stage polymerization to produce electrophoretic particles with optimum electrophoretic mobilities in dielectric media for developing high quality images.

The dielectric white electrophoretic particles 22 of highly crosslinked polymer with controlled surface functionality are prepared by a two-stage dispersion polymerization technique. As will be recognized by a person skilled in the art, two-stage dispersion polymerization involves dispersing vinyl monomers and a crosslinker in an organic solvent in which the monomers and crosslinker are soluble and then polymerizing the vinyl monomers and the crosslinker in the presence of a dispersion stabilizer and an initiator at elevated temperatures. The polymerized monomer is insoluble in the solvent, thereby forming polymer particles. The second stage functional monomer is copolymerized on the insoluble polymer particles by injecting the functional monomer at a later stage of polymerization.

EXAMPLE ONE

In an exemplary embodiment of the present invention, dielectric, white, electrophoretic, highly crosslinked polymer particles 22 with controlled surface functionality, are prepared by a two-stage dispersion polymerization technique. The polymerization recipe is listed in Table I.

Table I

<u>Materials</u>	<u>Weight (g)</u>
Methanol	100
divinylbenzene	5
styrene	5
2,2'-azobisisobutyronitrile	0.5
poly(vinyl pyrrolidone)	2
Acrylamide	0.5

Prior to use, the inhibitors of the monomer styrene and the crosslinker divinylbenzene are removed by washing with 10% NaOH aqueous solution several times, drying with calcium carbonate overnight at 0°C and then passing through a column containing an appropriate inhibitor remover. The inhibitor-free monomers and crosslinker are stored in a freezer for later use. In this and subsequent processes, the styrene is of the type commercially available from Fisher Scientific, Inc. and the divinylbenzene is of the type commercially produced by Aldrich Chemical, Co. The 2,2'-azobisisobutyronitrile (AIBN) and poly(vinyl pyrrolidone) (PVP) used as an initiator and stabilizer are manufactured by Kodak and GAF Co. respectively. The second stage monomer, acrylamide, and the dispersion medium, methanol, a reagent grade, are of the types commercially available from Fisher Scientific, Inc.

The styrene and divinylbenzene are mixed with methanol and charged to a closed container containing the AIBN and PVP which are carefully weighed. The closed container is purged with nitrogen by bubbling the gas through the solution for a certain time. The container is then warmed and

agitated for a desired reaction time. In one preferred embodiment, the mixture is tumbled at thirty revolutions per minute for eight hours at sixty degrees celsius. After eight hours tumbling, the second stage monomer, acrylamide, is injected into the container which continues to tumble at the same reaction condition for another desired reaction time. The final product made by the two-stage dispersion polymerization process is highly crosslinked poly(styrene-co-divinylbenzene) particles with polyacrylamide grafted on the surface. The particle size of the final particles are uniform and varied from 0.2 to 10  $\mu\text{m}$  depending upon the reaction media be used. The final particles are dielectric with good whiteness and have a density close to 1  $\text{g/cm}^3$ . The polymer particles are separated from the dispersion medium by centrifuging and decanting the dispersion medium.

To form black particles, the product of the previous process is mixed and tumbled with osmium tetroxide aqueous solution at room temperature for a desired reaction time. The osmium tetroxide reacts with and stains the residual double bonds of the poly(styrene-co-divinylbenzene) particles, thereby resulting in highly crosslinked polymer particles having a desired degree of blackness that can be used as the present invention electrophoretic particles 122. It should be understood that in place and stead of the osmium tetroxide, ruthenium tetroxide or other metal oxides may also be used.

By varying the polymerization recipe of Table I and by varying other reaction parameters of the method of manufacture, the physical characteristics of the white and black particles produced can be selectively altered as needed for a given application. The surface functionality of the final particles can be varied by introducing different functional monomers, such as vinyl acetate, methyl methacrylate, acrylonitrile, acrylamide, dimethylaminopropylmethacrylamide, and the like, at the second stage polymerization to produce poly(styrene-co-divinylbenzene) particles with basic surface characteristics which are suitable for positive charging in dielectric media.